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Chapter 1

INTRODUCTION

1.1 INTRODUCTION

Hydrology means the science of water. It is the science that deals with the occurrence, circulation and distribution of water of the earth and earth's atmosphere. As a branch of earth science, it is concerned with the water in streams and lakes, rainfall and snowfall, snow and ice on the land and water occurring below the earth's surface in the pores of the soil and rocks. In a general sense, hydrology is a very broad subject of an inter-disciplinary nature drawing support from allied sciences, such as meteorology, geology, statistics, chemistry, physics and fluid mechanics.

Hydrology is basically an applied science. To further emphasise the degree of applicability, the subject is sometimes classified as

1. **Scientific hydrology**—the study which is concerned chiefly with academic aspects.
2. **Engineering or applied hydrology**—a study concerned with engineering applications.

In a general sense engineering hydrology deals with (i) estimation of water resources, (ii) the study of processes such as precipitation, runoff, evapotranspiration and their interaction and (iii) the study of problems such as floods and droughts, and strategies to combat them.

This book is an elementary treatment of engineering hydrology with descriptions that aid in a qualitative appreciation and techniques which enable a quantitative evaluation of the hydrologic processes that are of importance to a civil engineer.

1.2 HYDROLOGIC CYCLE

Water occurs on the earth in all its three states, viz. liquid, solid and gaseous, and in various degrees of motion. Evaporation of water from water bodies such as oceans and lakes, formation and movement of clouds, rain and snowfall, streamflow and groundwater movement are some examples of the dynamic aspects of water. The various aspects of water related to the earth can be explained in terms of a cycle known as the *hydrologic cycle.*

Figure 1.1 is a schematic representation of the hydrologic cycle. A convenient starting point to describe the cycle is in the oceans. Water in the oceans evaporate due to the heat energy provided by solar radiation. The water vapour moves upwards and forms clouds. While much of the clouds condense and fall back to the oceans as rain, a part of the clouds is driven to the land areas by winds. There they condense and *precipitate* onto the land mass as rain, snow, hail, sleet, etc. A part of the precipitation

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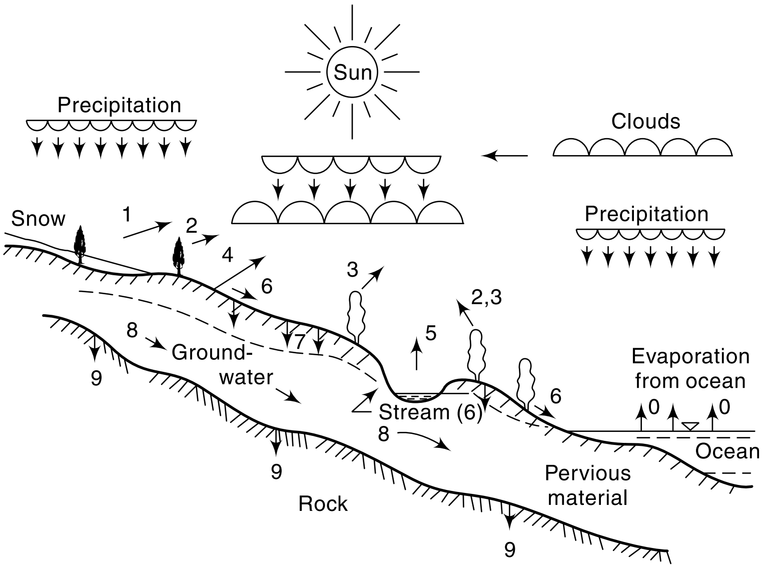

0 = Evaporation from ocean
1 = Raindrop evaporation
2 = Interception
3 = Transpiration
4 = Evaporation from land
5 = Evaporation from water bodies
6 = Surface runoff
7 = Infiltration
8 = Groundwater
9 = Deep percolation

Fig. 1.1 The Hydrologic Cycle

may *evaporate* back to the atmosphere even while falling. Another part may be *intercepted* by vegetation, structures and other such surface modifications from which it may be either evaporated back to atmosphere or move down to the ground surface.

A portion of the water that reaches the ground enters the earth's surface through *infiltration,* enhance the moisture content of the soil and reach the groundwater body. Vegetation sends a portion of the water from under the ground surface back to the atmosphere through the process of *transpiration.* The precipitation reaching the ground surface after meeting the needs of infiltration and evaporation moves down the natural slope over the surface and through a network of gullies, streams and rivers to reach the ocean. The groundwater may come to the surface through springs and other outlets after spending a considerably longer time than the surface flow. The portion of the precipitation which by a variety of paths above and below the surface of the earth reaches the stream channel is called *runoff.* Once it enters a stream channel, runoff becomes *stream flow.*

The sequence of events as above is a simplistic picture of a very complex cycle that has been taking place since the formation of the earth. It is seen that the hydrologic cycle is a very vast and complicated cycle in which there are a large number of paths of varying time scales. Further, it is a continuous recirculating cycle in the sense that there is neither a beginning nor an end or a pause. Each path of the hydrologic cycle involves one or more of the following aspects: (i) transportation of water, (ii) temporary storage and (iii) change of state. For example, (a) the process of rainfall has the

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change of state and transportation and (b) the groundwater path has storage and transportation aspects.

The main components of the hydrologic cycle can be broadly classified as *transportation (flow) components* and *storage components* as below:

Transportation components	Storage components
Precipitation	Storage on the land surface (Depression storage, Ponds, Lakes, Reservoirs, etc)
Evaporation	Soil moisture storage
Transpiration	Groundwater storage
Infiltration	
Runoff	

Schematically the interdependency of the transportation components can be represented as in Fig. 1.2. The quantities of water going through various individual paths of the hydrological cycle in a given system can be described by the continuity principle known as *water budget equation* or *hydrologic equation.*

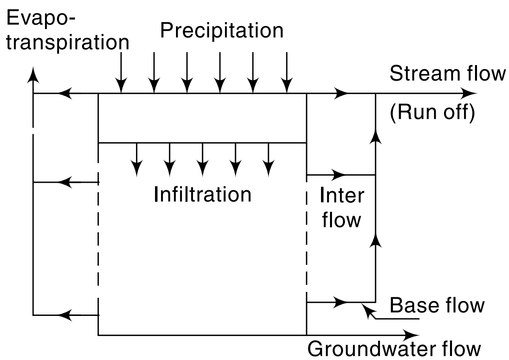

Fig. 1.2 Transportation Components of the Hydrologic Cycle

It is important to note that the total water resources of the earth are constant and the sun is the source of energy for the hydrologic cycle. A recognition of the various processes such as evaporation, precipitation and groundwater flow helps one to study the science of hydrology in a systematic way. Also, one realises that man can interfere with virtually any part of the hydrologic cycle, e.g. through artificial rain, evaporation suppression, change of vegetal cover and land use, extraction of groundwater, etc. Interference at one stage can cause serious repercussions at some other stage of the cycle.

The hydrological cycle has important influences in a variety of fields including agriculture, forestry, geography, economics, sociology and political scene. Engineering applications of the knowledge of the hydrologic cycle, and hence of the subjects of hydrology, are found in the design and operation of projects dealing with water supply, irrigation and drainage, water power, flood control, navigation, coastal works, salinity control and recreational uses of water.

1.3 WATER BUDGET EQUATION

Catchment Area

The area of land draining into a stream or a water course at a given location is known as *catchment area.* It is also called as *drainage area* or *drainage basin.* In USA, it is known as *watershed.* A catchment area is separated form its neighbouring areas by a

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ridge called *divide* in USA and *watershed* in UK (Fig. 1.3). The areal extent of the catchment is obtained by tracing the ridge on a topographic map to delineate the catchment and measuring the area by a *planimeter*. It is obvious that for a river while mentioning the catchment area the station to which it pertains (Fig. 1.3) must also be mentioned. It is normal to assume the groundwater divide to coincide with the surface divide. Thus, the catchment area affords a logical and convenient unit to study various aspects relating to the hydrology and water resources of a region. Further it is probably the singlemost important drainage characteristic used in hydrological analysis and design.

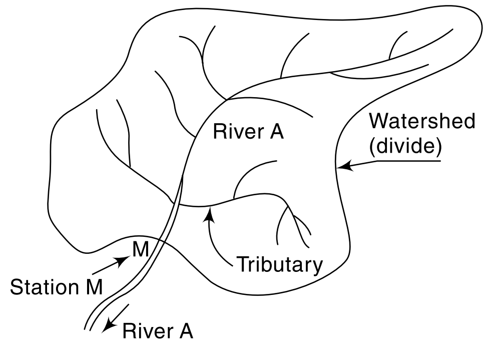

Fig. 1.3 Schematic Sketch of Catchment of River A at Station M

Water Budget Equation

For a given problem area, say a catchment, in an interval of time Δt, the continuity equation for water in its various phases is written as

Mass inflow – mass outflow = change in mass storage

If the density of the inflow, outflow and storage volumes are the same

$$\mathcal{V}_i - \mathcal{V}_0 = \Delta S \tag{1.1}$$

where $\mathcal{V}_i$ = inflow volume of water into the problem area during the time period, $\mathcal{V}_0$ = outflow volume of water from the problem area during the time period, and ΔS = change in the storage of the water volume over and under the given area during the given period. In applying this continuity equation [Eq. (1.1)] to the paths of the hydrologic cycle involving change of state, the volumes considered are the equivalent volumes of water at a reference temperature. In hydrologic calculations, the volumes are often expressed as average depths over the catchment area. Thus, for example, if the annual stream flow from a 10 km^2 catchment is 10^7 m^3, it corresponds to a depth of $\left(\dfrac{10^7}{10 \times 10^6}\right)$ = 1 m = 100 cm. Rainfall, evaporation and often runoff volumes are expressed in units of depth over the catchment.

While realizing that all the terms in a hydrological water budget may not be known to the same degree of accuracy, an expression for the water budget of a catchment for a time interval Δt is written as

$$P - R - G - E - T = \Delta S \tag{1.2-a}$$

In this P = precipitation, R = surface runoff, G = net groundwater flow out of the catchment, E = evaporation, T = transpiration and ΔS = change in storage.

The storage S consists of three components as

$$S = S_s + S_{sm} + S_g$$

where S_s = surface water storage

S_{sm} = water in storage as soil moisture and

S_g = water in storage as groundwater.

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Thus in Eq. (1.2-a) $\Delta S = \Delta S_s + \Delta S_{sm} + \Delta S_g$

All terms in Eq. (1.2-a) have the dimensions of volume. Note that all these terms can be expressed as depth over the catchment area (e.g. in centimetres), and in fact this is a very common unit.

In terms of rainfall–runoff relationship, Eq. (1.2-a) can be represented as

$$R = P - L \tag{1.2-b}$$

where L = Losses = water not available to runoff due to infiltration (causing addition to soil moisture and groundwater storage), evaporation, transpiration and surface storage. Details of various components of the water budget equation are discussed in subsequent chapters. Note that in Eqs (1.2-a and b) the net import of water into the catchment, from sources outside the catchment, by action of man is assumed to be zero.

Example 1.1 *A lake had a water surface elevation of 103.200 m above datum at the beginning of a certain month. In that month the lake received an average inflow of 6.0 m^3/s from surface runoff sources. In the same period the outflow from the lake had an average value of 6.5 m^3/s. Further, in that month, the lake received a rainfall of 145 mm and the evaporation from the lake surface was estimated as 6.10 cm. Write the water budget equation for the lake and calculate the water surface elevation of the lake at the end of the month. The average lake surface area can be taken as 5000 ha. Assume that there is no contribution to or from the groundwater storage.*

Solution: In a time interval Δt the water budget for the lake can be written as

Input volume – output volume = change in storage of the lake

$$(\bar{I}\,\Delta t + PA) - (\bar{Q}\,\Delta t + EA) = \Delta S$$

where $\bar{I}$ = average rate of inflow of water into the lake, $\bar{Q}$ = average rate of outflow from the lake, P = precipitation, E = evaporation, A = average surface area of the lake and ΔS = change in storage volume of the lake.

Here Δt = 1 month = $30 \times 24 \times 60 \times 60 = 2.592 \times 10^6$ s = 2.592 Ms

In one month:

$$\text{Inflow volume} = \bar{I}\,\Delta t = 6.0 \times 2.592 = 15.552 \text{ M m}^3$$

$$\text{Outflow volume} = \bar{Q}\,\Delta t = 6.5 \times 2.592 = 16.848 \text{ M m}^3$$

$$\text{Input due to precipitation} = PA = \frac{14.5 \times 5000 \times 100 \times 100}{100 \times 10^6} \text{ M m}^3 = 7.25 \text{ M m}^3$$

$$\text{Outflow due to evaporation} = EA = \frac{6.10}{100} \times \frac{5000 \times 100 \times 100}{10^6} = 3.05 \text{ M m}^3$$

Hence $\Delta S = 15.552 + 7.25 - 16.848 - 3.05 = 2.904$ M m^3

Change in elevation $\Delta z = \dfrac{\Delta S}{A} = \dfrac{2.904 \times 10^6}{5000 \times 100 \times 100} = 0.058$ m

New water surface elevation at the end of the month = 103.200 + 0.058
= 103.258 m above the datum.

Example 1.2 *A small catchment of area 150 ha received a rainfall of 10.5 cm in 90 minutes due to a storm. At the outlet of the catchment, the stream draining the catchment was dry before the storm and experienced a runoff lasting for 10 hours with an average discharge of 1.5 m^3/s. The stream was again dry after the runoff event. (a) What is the amount of water which was not available to runoff due to combined effect of infiltration, evaporation and transpiration? What is the ratio of runoff to precipitation?*

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SOLUTION: The water budget equation for the catchment in a time Δt is

$$R = P - L \quad (1.2\text{-b})$$

where L = Losses = water not available to runoff due to infiltration (causing addition to soil moisture and groundwater storage), evaporation, transpiration and surface storage. In the present case Δt = duration of the runoff = 10 hours.

Note that the rainfall occurred in the first 90 minutes and the rest 8.5 hours the precipitation was zero.

(a) P = Input due to precipitation in 10 hours
$= 150 \times 100 \times 100 \times (10.5/100) = 157{,}500 \text{ m}^3$
R = runoff volume = outflow volume at the catchment outlet in 10 hours
$= 1.5 \times 10 \times 60 \times 60 = 54{,}000 \text{ m}^3$
Hence losses $L = 157{,}500 - 54{,}000 = 103{,}500 \text{ m}^3$

(b) Runoff/rainfall = 54,000/157,500 = 0.343
(This ratio is known as *runoff coefficient* and is discussed in Chapter 5)

1.4 WORLD WATER BALANCE

The total quantity of water in the world is estimated to be about 1386 million cubic kilometres (M km^3). About 96.5% of this water is contained in the oceans as saline water. Some of the water on the land amounting to about 1% of the total water is also saline. Thus only about 35.0 M km^3 of fresh water is available. Out of this about 10.6 M km^3 is both liquid and fresh and the remaining 24.4 M km^3 is contained in frozen state as ice in the polar regions and on mountain tops and glaciers. An estimated distribution of water on the earth is given in Table 1.1.

Table 1.1 Estimated World Water Quantities

Item	Area (M km^2)	Volume (M km^3)	Percent total water	Percent fresh water
1. Oceans	361.3	1338.0	96.5	—
2. Groundwater				
(a) fresh	134.8	10.530	0.76	30.1
(b) saline	134.8	12.870	0.93	—
3. Soil moisture	82.0	0.0165	0.0012	0.05
4. Polar ice	16.0	24.0235	1.7	68.6
5. Other ice and snow	0.3	0.3406	0.025	1.0
6. Lakes				
(a) fresh	1.2	0.0910	0.007	0.26
(b) saline	0.8	0.0854	0.006	—
7. Marshes	2.7	0.01147	0.0008	0.03
8. Rivers	148.8	0.00212	0.0002	0.006
9. Biological water	510.0	0.00112	0.0001	0.003
10. Atmospheric water	510.0	0.01290	0.001	0.04
Total: (a) All kinds of water	510.0	1386.0	100.0	
(b) Fresh water	148.8	35.0	2.5	100.0

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The global annual water balance is shown in Table 1.2.

Table 1.2 Global Annual Water Balance

Item	Ocean	Land
1. Area (M km^2)	361.30	148.8
2. Precipitation (km^3/year)	458,000	119,000
(mm/year)	1270	800
3. Evaporation (km^3/year)	505,000	72,000
(mm/year)	1400	484
4. Runoff to ocean		
(i) Rivers (km^3/year)		44,700
(ii) Groundwater (km^3/year)		2,200
Total Runoff (km^3/year)		47,000
(mm/year)		316

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It is seen from Table 1.2 that the annual evaporation from the world's oceans and inland areas are 0.505 and 0.072 M km^3 respectively. Thus, over the oceans about 9% more water evaporates than that falls back as precipitation. Correspondingly, there will be excess precipitation over evaporation on the land mass. The differential, which is estimated to be about 0.047 M km^3 is the runoff from land mass to oceans and groundwater outflow to oceans. It is interesting to know that less than 4% of this total river flow is used for irrigation and the rest flows down to sea.

These estimates are only approximate and the results from different studies vary; the chief cause being the difficulty in obtaining adequate and reliable data on a global scale.

The volume in various phases of the hydrologic cycle (Table 1.1) as also the rate of flow in that phase (Table 1.2) do vary considerably. The average duration of a particle of water to pass through a phase of the hydrologic cycle is known as the *residence time* of that phase. It could be calculated by dividing the volume of water in the phase by the average flow rate in that phase. For example, by assuming that all the surface runoff to the oceans comes from the rivers,

From Table 1.1, the volume of water in the rivers of the world = 0.00212 M km^3

From Table 1.2, the average flow rate of water in global rivers = 44700 km^3/year

Hence residence time of global rivers, T_r = 2120/44700 = 0.0474 year = 17.3 days.

Similarly, the residence time for other phases of the hydrological cycle can be calculated (Prob. 1.6). It will be found that the value of T_r varies from phase to phase. In a general sense the shorter the residence time the greater is the difficulty in predicting the behaviour of that phase of the hydrologic cycle.

Annual water balance studies of the sub-areas of the world indicate interesting facts. The water balance of the continental land mass is shown in Table 1.3(a). It is interesting to see from this table that Africa, in spite of its equatorial forest zones, is

the driest continent in the world with only 20% of the precipitation going as runoff. On the other hand, North America and Europe emerge as continents with highest runoff. Extending this type of analysis to a smaller land mass, viz. the Indian subcontinent, the long term average runoff for India is found to be 46%.

Table 1.3(a) Water Balance of Continents[2] mm/year

Continent	Area (M km^2)	Precipitation	Total runoff	Runoff as % of precipitation	Evaporation
Africa	30.3	686	139	20	547
Asia	45.0	726	293	40	433
Australia	8.7	736	226	30	510
Europe	9.8	734	319	43	415
N. America	20.7	670	287	43	383
S. America	17.8	1648	583	35	1065

Water balance studies on the oceans indicate that there is considerable transfer of water between the oceans and the evaporation and precipitation values vary from one ocean to another (Table 1.3(b)).

Table 1.3(b) Water Balance of Oceans[2] mm/year

Ocean	Area (M km^2)	Precipitation	Inflow from adjacent continents	Evaporation	Water exchange with other oceans
Atlantic	107	780	200	1040	–60
Arctic	12	240	230	120	350
Indian	75	1010	70	1380	–300
Pacific	167	1210	60	1140	130

Each year the rivers of the world discharge about 44,700 km^3 of water into the oceans. This amounts to an annual average flow of 1.417 Mm^3/s. The world's largest river, the Amazon, has an annual average discharge of 200,000 m^3/s, i.e. one-seventh of the world's annual average value. India's largest river, the Brahmaputra, and the second largest, the Ganga, flow into the Bay of Bengal with a mean annual average discharges of 16,200 m^3/s and 15,600 m^3/s respectively.

1.5 HISTORY OF HYDROLOGY

Water is the prime requirement for the existence of life and thus it has been man's endeavour from time immemorial to utilise the available water resources. History has instances of civilizations that flourished with the availability of dependable water supplies and then collapsed when the water supply failed. Numerous references exist in Vedic literature to groundwater availability and its utility. During 3000 BC groundwater development through wells was known to the people of the Indus Valley civilizations as revealed by archaeological excavations at Mohenjodaro. Quotations in ancient Hindu scriptures indicate the existence of the knowledge of the hydrologic cycle even as far back as the Vedic period. The first description of the raingauge and its use is contained

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in the *Arthashastra* by Chanakya (300 BC). Varahamihira's (AD 505–587) *Brihatsamhita* contains descriptions of the raingauge, wind vane and prediction procedures for rainfall. Egyptians knew the importance of the stage measurement of rivers and records of the stages of the Nile dating back to 1800 BC have been located. The knowledge of the hydrologic cycle came to be known to Europe much later, around AD 1500.

Chow[1] classifies the history of hydrology into eight periods as:

1. Period of speculation—prior to AD 1400
2. Period of observation—1400–1600
3. Period of measurement—1600–1700
4. Period of experimentation—1700–1800
5. Period of modernization—1800–1900
6. Period of empiricism—1900–1930
7. Period of rationalization—1930–1950
8. Period of theorization—1950–to–date

Most of the present-day science of hydrology has been developed since 1930, thus giving hydrology the status of a young science. The worldwide activities in water-resources development since the last few decades by both developed and developing countries aided by rapid advances in instrumentation for data acquisition and in the computer facilities for data analysis have contributed towards the rapid growth rate of this young science.

1.6 APPLICATIONS IN ENGINEERING

Hydrology finds its greatest application in the design and operation of water-resources engineering projects, such as those for (i) irrigation, (ii) water supply, (iii) flood control, (iv) water power, and (v) navigation. In all these projects hydrological investigations for the proper assessment of the following factors are necessary:

1. The capacity of storage structures such as reservoirs.
2. The magnitude of flood flows to enable safe disposal of the excess flow.
3. The minimum flow and quantity of flow available at various seasons.
4. The interaction of the flood wave and hydraulic structures, such as levees, reservoirs, barrages and bridges.

The hydrological study of a project should necessarily precede structural and other detailed design studies. It involves the collection of relevant data and analysis of the data by applying the principles and theories of hydrology to seek solutions to practical problems.

Many important projects in the past have failed due to improper assessment of the hydrological factors. Some typical failures of hydraulic structures are: (i) overtopping and consequent failure of an earthen dam due to an inadequate spillway capacity, (ii) failure of bridges and culverts due to excess flood flow and (iii) inability of a large reservoir to fill up with water due to overestimation of the stream flow. Such failure, often called *hydrologic failures* underscore the uncertainty aspect inherent in hydrological studies.

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Various phases of the hydrological cycle, such as rainfall, runoff, evaporation and transpiration are all nonuniformly distributed both in time and space. Further, practically all hydrologic phenomena are complex and at the present level of knowledge, they can at best be interpreted with the aid of probability concepts. Hydrological events are treated as random processes and the historical data relating to the event are analysed by statistical methods to obtain information on probabilities of occurrence of various events. The probability analysis of hydrologic data is an important component of present-day hydrological studies and enables the engineer to take suitable design decisions consistent with economic and other criteria to be taken in a given project.

1.7 SOURCES OF DATA

Depending upon the problem at hand, a hydrologist would require data relating to the various relevant phases of the hydrological cycle playing on the problem catchment. The data normally required in the studies are:

- Weather records—temperature, humidity and wind velocity
- Precipitation data
- Stream flow records
- Evaporation and evapotranspiration data
- Infiltration characteristics of the study area
- Soils of the area
- Land use and land cover
- Groundwater characteristics
- Physical and geological characteristics of the area
- Water quality data

In India, hydro-meteorological data are collected by the India Meteorological Department (IMD) and by some state government agencies. The Central Water Commission (CWC) monitors flow in major rivers of the country. Stream flow data of various rivers and streams are usually available from the State Water Resources/Irrigation Department. Groundwater data will normally be available with Central Groundwater Board (CGWB) and state Government groundwater development agencies. Data relating evapotranspiration and infiltration characteristics of soils will be available with State Government organizations such as Department of Agriculture, Department of Watershed development and Irrigation department. The physical features of the study area have to be obtained from a study of topographical maps available with the Survey of India. The information relating to geological characteristics of the basin under study will be available with the Geological Survey of India and the state Geology Directorate. Information relating to soils at an area are available from relevant maps of National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), 1996. Further additional or specific data can be obtained from the state Agriculture Department and the state Watershed Development Department. Land use and land cover data would generally be available from state Remote sensing Agencies. Specific details will have to be derived through interpretation of multi-spectral multi-season satellite images available from National Remote Sensing Agency (NRSA) of Government of India. Central and State Pollution Control Boards, CWC and CGWB collect water quality data.

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Revision Questions

1.1 Describe the Hydrologic cycle. Explain briefly the man's interference in various parts of this cycle.

1.2 Discuss the hydrological water budget with the aid of examples.

1.3 What are the significant features of global water balance studies?

1.4 List the major activities in which hydrological studies are important.

1.5 Describe briefly the sources of hydrological data in India.

Problems

1.1 Two and half centimetres of rain per day over an area of 200 km^2 is equivalent to average rate of input of how many cubic metres per second of water to that area?

1.2 A catchment area of 140 km^2 received 120 cm of rainfall in a year. At the outlet of the catchment the flow in the stream draining the catchment was found to have an average rate of 2.0 m^3/s for 3 months, 3.0 m^3/s for 6 months and 5.0 m^3/s for 3 months. (i) What is the runoff coefficient of the catchment? (ii) If the afforestation of the catchment reduces the runoff coefficient to 0.50, what is the increase in the abstraction from precipitation due to infiltration, evaporation and transpiration, for the same annual rainfall of 120 cm?

1.3 Estimate the constant rate of withdrawal from a 1375 ha reservoir in a month of 30 days during which the reservoir level dropped by 0.75 m in spite of an average inflow into the reservoir of 0.5 Mm^3/day. During the month the average seepage loss from the reservoir was 2.5 cm, total precipitation on the reservoir was 18.5 cm and the total evaporation was 9.5 cm.

1.4 A river reach had a flood wave passing through it. At a given instant the storage of water in the reach was estimated as 15.5 ha.m. What would be the storage in the reach after an interval of 3 hours if the average inflow and outflow during the time period are 14.2 m^3/s and 10.6 m^3/s respectively?

1.5 A catchment has four sub-areas. The annual precipitation and evaporation from each of the sub-areas are given below.
Assume that there is no change in the groundwater storage on an annual basis and calculate for the whole catchment the values of annual average (i) precipitation, and (ii) evaporation. What are the annual runoff coefficients for the sub-areas and for the total catchment taken as a whole?

Sub-area	Area Mm^2	Annual precipitation mm	Annual evaporation mm
A	10.7	1030	530
B	3.0	830	438
C	8.2	900	430
D	17.0	1300	600

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1.6 Estimate the residence time of
(a) Global atmospheric moisture.
(b) Global groundwater by assuming that only the fresh groundwater runs off to the oceans.
(c) Ocean water.

Objective Questions

1.1 The percentage of earth covered by oceans is about
(a) 31% (b) 51% (c) 71% (d) 97%

1.2 The percentage of total quantity of water in the world that is saline is about
(a) 71% (b) 33% (c) 67% (d) 97%

1.3 The percentage of total quantity of fresh water in the world available in the liquid form is about
(a) 30% (b) 70% (c) 11% (d) 51%

1.4 If the average annual rainfall and evaporation over land masses and oceans of the earth are considered it would be found that
(a) over the land mass the annual evaporation is the same as the annual precipitation
(b) about 9% more water evaporates from the oceans than what falls back on them as precipitation
(c) over the ocean about 19% more rain falls than what is evaporated
(d) over the oceans about 19% more water evaporates than what falls back on them as precipitation.

1.5 Considering the ratio of annual precipitation to runoff = r_0 for all the continents on the earth,
(a) Asia has the largest value of the ratio r_0.
(b) Europe has the smallest value of r_0.
(c) Africa has the smallest value of r_0.
(d) Australia has the smallest value of r_0.

1.6 In the hydrological cycle the average residence time of water in the global
(a) atmospheric moisture is larger than that in the global rivers
(b) oceans is smaller than that of the global groundwater
(c) rivers is larger than that of the global groundwater
(d) oceans is larger than that of the global groundwater.

1.7 A watershed has an area of 300 ha. Due to a 10 cm rainfall event over the watershed a stream flow is generated and at the outlet of the watershed it lasts for 10 hours. Assuming a runoff/rainfall ratio of 0.20 for this event, the average stream flow rate at the outlet in this period of 10 hours is
(a) 1.33 m^3/s (b) 16.7 m^3/s (c) 100 m^3/minute (d) 60,000 m^3/h

1.8 Rainfall of intensity of 20 mm/h occurred over a watershed of area 100 ha for a duration of 6 h. measured direct runoff volume in the stream draining the watershed was found to be 30,000 m^3. The precipitation not available to runoff in this case is
(a) 9 cm (b) 3 cm (c) 17.5 mm (d) 5 mm

1.9 A catchment of area 120 km^2 has three distinct zones as below:

Zone	Area (km^2)	Annual runoff (cm)
A	61	52
B	39	42
C	20	32

The annual runoff from the catchment, is
(a) 126.0 cm (b) 42.0 cm (c) 45.4 cm (d) 47.3 cm